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MACHINE CASTING OF FERROUS ALLOYS

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MACHINE CASTING OF FERROUS ALLOYS

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This is the fourth interim report describing research conducted at Massachusetts Institute of Technology as part of a joint university-industry research program on casting of ferrous alloys. It covers the period of the thirtieth to the thirty-sixth month of four-year program.

During this period, major emphasis has been on the development of the Thixocasting process. The Continuous Rheocaster has been modified to

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improve performance and a Softness Indicator has been developed to control the Thixocasting reheating stage, thereby eliminating thermocouples. Following production of more than 1000 pounds of the model Copper Alloy 905, more than 800 pounds of AISI 440C and 304 stainless steel have been used to produce more than 500 Thixocastings in the copper alloy and over 400 stainless steel Thixocastings. In the course of this work, casting parameter optimization has shown that good Thixocasting practice for these alloys requires equivalent or lower casting pressures than conventional liquid practice and considerable lower metal ingate velocities.

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Interim Technical Report

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December 1975

by

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ABSTRACT

This is the fourth interim report describing research conducted at Massachusetts Institute of Technology as part of a joint university-industry research program on casting of ferrous alloys. It covers the period of the thirtieth to the thirty-sixth month of four-year program.

During this period, major emphasis has been on the development of the Thixocasting process. The Continuous Rheocaster has been modified to improve performance and a Softness Indicator has been developed to control the Thixocasting reheating stage, thereby eliminating thermocouples. Following production of more than 1000 pounds of the model Copper Alloy 905, more than 800 pounds of AISI 440C and 304 stainless steel have been Rheocast in ingot form. Charges, cut from these ingots, have been used to produce more than 500 Thixocastings in the copper alloy and over 400 stainless steel Thixocastings. In the course of this work, casting parameter optimization has shown that good Thixocasting practice for these alloys requires equivalent or lower casting pressures than conventional liquid practice and considerably lower metal ingate velocities.

Introduction

In January, 1973, a joint university-industry research activity was undertaken to develop an economical method of machine casting ferrous alloys. The portion of this program being conducted at Massachusetts Institute of Technology has been primarily on machine casting of semi-solid alloys, into reusable metal dies. A variety of casting concepts have been explored as reported herein and in previous reports, (1,2) but major emphasis of the work has been on two processes: Rheocasting and Thixocasting. In Rheocasting, a semi-solid slurry of a metal alloy is produced by vigorous agitation of a solidifying melt. This highly fluid slurry, typically the consistency of heavy machine oil at fractions solidified up to 0.5, is then cast directly to shape. In Thixocasting, fully solid ingots are first made from the semi-solid slurry and "charges" from these ingots are then reheated to the liquid-solid range and cast. Because the alloy slurries are thixotropic, these reheated charges retain their shape, behaving as soft solids, during transfer to the die casting machine. The high shear rates the charge undergoes within the gate entry and land area of the casting cavity reduce its viscosity to a level at which it flows smoothly into the cavity.

The previous report in this series[1] and associated paper[2] summarized the program to date (period ending July 1975) at which point a pilot scale Thixocasting system had been demonstrated using as a model Copper Alloy 905. Preliminary production of Rheocast 440C stainless steel ingots was also reported. This current report summarizes the next 6 month period (period ending December 31, 1975), in which the final phase of the program has been entered.

The Thixocasting process has been uprated to operate at pilot plant scale with 440C and 304 stainless steel in preparation for large scale runs which are planned for the next 12 month period. Additional work continues at a low rate of effort to develop new forming processes using the model Sn-Pb Continuous Rheocaster and electromagnetic discharge devices to replace the plunger of a die casting system. Further experimental and theoretical analysis of heat transfer in the die casting process is also underway following completion of initial exploratory experiments.[3,4]

Continuous Rheocasting

During this report period the Continuous Rheocasting equipment has been used to produce stainless steel ingots which serve as charging stock for Thixocasting. The ingots, as Rheocast, are 1 and 1/4 inches in diameter by 6 inches long and weigh about 2 pounds. They are later sectioned into three "charges" of about 0.7 pounds.

While the equipment remains substantially as described in the last sponsor's report,[1] modifications have been made in this report period to improve performance. Firstly, a lining of 1/8 inch thick recrystallized alumina has been placed in the mixing chamber of the Rheocaster. This high density alumina lining has eliminated erosion of the inside wall of the mixing chamber during the production of stainless steel slurries. Secondly, a meter has been installed to give direct readout of the amperage required by the D.C. motor which drives the mixing rotor. At a given cooling rate and mixing rate, the amperage gives an indication of the apparent viscosity (and, therefore, the fraction solid) of the slurry within the chamber. During the current ingot production runs, the amperage required for mixing is being logged and correlated with the fraction solid of the slurry ingots being produced.

The ingot making procedure has been described in the last sponsor's report.[1] More than 1000 pounds of Rheocast Copper Alloy 905 ingots have been produced in typical continuous runs of 200 pounds. These ingots have been used as feed stock during the development stage of the Thixocasting system.

Current Rheocast ingot production has been in 2 stainless steel alloys--AISI types 440C and 304. To date, more than 500 pounds of 440C ingots and 300 pounds of 304 stainless ingots have been produced. Figure 1 shows the typical

microstructure of 304 stainless slurry which was water-quenched as it exited from the Continuous Rheocaster. Figure 2 shows the typical microstructure of a 304 stainless steel Rheocast ingot.

Thixocasting

The Thixocasting process route for die casting partially solidified slurries of high temperature alloys is shown schematically in Figure 3. The basic procedures and equipment remain essentially as described in a previous report[1] except for the introduction of the Softness Indicator shown in Figure 4, and the adoption of reusable, thin wall, clay graphite crucibles to contain the charge during reheating and transfer. The Softness Indicator was developed to eliminate temperature control of the charge reheating stage. Thus, high temperature, platinum based thermocouples which are expensive and undesirable for a machine casting operation are not required.

The Softness Indicator consists of a simple weighted silica probe 1/8 inch in diameter with a hemispherical base which rests upon the charge while it is heating. Calibration curves, produced by isothermal holding experiments on Copper Alloy 905 are shown in Figure 5. These show how the mean probe velocity measured over 0.2 to 0.5 inches of travel, increases with increasing charge temperature in the semi-solid range. During the reheating of the charges for Thixocasting, one such curve as shown in Figure 5 is traversed and thus, with appropriate choice of probe weight, the probe travel (or mean velocity) is a reliable estimate of charge volume fraction solidified.

Using the Softness Indicator to consistently produce reheated charges containing between 0.45 and 0.55 volume fraction solid, more than five hundred die castings have been made in the model Copper Alloy 905 in runs which varied in lengths from a few test castings to more than one hundred castings. Since the reheated charges are thixotropic they can be handled much like soft solids. Figure 6, shows a Copper Alloy 905 charge just prior to injection which has retained its cylindrical ingot shape. The high shear the charge undergoes at the gate entry then reduces its' viscosity to a level at which it will flow homogeneously into the die cavity.

Some of the castings produced can be seen in Figure 7, in various stages of finishing. The shapes are the M16 rifle hammer or preliminary simulated versions of it used in casting optimization. This optimization of the casting parameters was made possible by the addition to the casting system of a Honeywell Visicorder die casting monitoring system. This multichannel transducer/oscillograph device permits continuous measurement of the hydraulic pressures driving the injection piston as well as the velocity and displacement of the piston. From a knowledge of the cavity and shot sleeve geometry these measurements allow calculation of both metal ingate velocity and metal casting pressure. Figure 8 shows for Copper Alloy 905 the results of the casting parameter optimization for the simulated M16 cavity shown in Figure 7. The H-13 dies were maintained at 275°C preheat. Figure 8 has been constructed using an average casting rating based on the sum of the radiographic soundness rating as employed previously[1] and a surface quality rating which also ran from 1 (excellent) through 5 (non-fill). It shows that to produce good thixocastings in Copper Alloy 905 requires equivalent or lower metal cavity pressures than the conventional liquid die casting approach and substantially lower metal ingate velocities which for bronzes, for example, are typically 70 to 150 ft sec^{-1}, at 6000 to 20,000 psi.[5] Furthermore, as the histogram of Figure 9 shows, the Thixocast parts are consistently internally sound as shown in previous reports.[6]

Following this preliminary work with the model Copper Alloy 905, the Thixocasting system has been operated with both 440C stainless steel and more recently 304 stainless steel. Initially using 440C stainless steel, the casting parameter optimization was repeated for the simulated M16 cavity to produce the results shown in Figure 10. Once again the annealed H-13 steel dies were preheated to only 275°C. These results are essentially similar to Figure 8.

Because of these results, the hydraulic control system of the die casting machine was modified to produce the desirable slow metal ingate velocities without undue delay in the shot chamber (with piston speeds of only 8 to 10 inch sec^{-1}a full piston stroke at constant velocity required approximately 1 1/2 seconds before the modification). Following the production of the castings reported in Figure 10 several hundred stainless steel castings have now been produced in runs of from 10 castings to about 100 castings. The total castings to date are summarized in Table 1 with micrographs from representative castings shown in Figure 11 and 12. Since the majority of this casting program to date has been completed in annealed H-13 dies, estimates of die lives have not been made. Now that the Thixocasting system has been demonstrated for steels, die life estimates will now be made using regular, fully hardened die materials.

Summary Conclusions

1. The Continuous Rheocaster has been modified to improve performance and operated to produce more than 800 pounds of AISI 440C and 304 stainless steel.
2. The Thixocasting system has been fully demonstrated using as a model Copper Alloy 905. Over 500 castings have been produced of consistently good surface and internal quality in line with earlier work.
3. Casting parameter optimization experiments for both the model Copper Alloy 905 and 440C stainless steel show that to produce good Thixocastings from H-13 steel dies preheated to 275°C requires equivalent or lower pressures than the conventional liquid process and considerably lower metal ingate velocities.
4. A Softness Indicator has been developed which has eliminated the need for thermocouples to control the charge reheating stage. It is simple in construction and easy to maintain and permits consistent production of reheated charges for Thixocasting of both copper and ferrous alloys.
5. The Thixocasting system has been fully demonstrated for ferrous alloys and several hundred stainless steel castings have been produced.

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1. M.C. Flemings et al., "Machine Casting of Ferrous Alloys," Interim Technical Report AMMRC CTR 74-55, ARPA Contract DAAG46-73-C-0110, 1 July 74 - 30 June 1975, prepared for AMMRC, Watertown, Massachusetts.

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3. D.G. Backman, Sc.D. Thesis, "The Machine Casting of High Temperature Semi-solid Metals", Massachusetts Institute of Technology.

4. D.G. Backman, R. Mehrabian, M.C. Flemings, "Die Thermal Behavior in Machine Casting of Partially Solid High Temperature Alloys", presented at 105th AIME meeting, Las Vegas, Nevada (1976).

5. A.A. Machonis, Ed., G.A. Herman, J.F. Wallace, "Copper Alloy Pressure Die Casting", International Copper Research Association, Inc., New York, New York (1975).

6. M.C. Flemings et al., "Machine Casting of Ferrous Alloys", Interim Technical Report AMMRC CTR 74-27, DAAG46-73-C-0110, 1 January 74 - 30 June 1974, prepared for AMMRC, Watertown, Massachusetts.

TABLE I

Number of Castings Produced

	Copper Alloy 905	440C Stainless Steel	304 Stainless Steel
Simulated M16 Hammer	530	270	
M16 Hammer	20	150	20

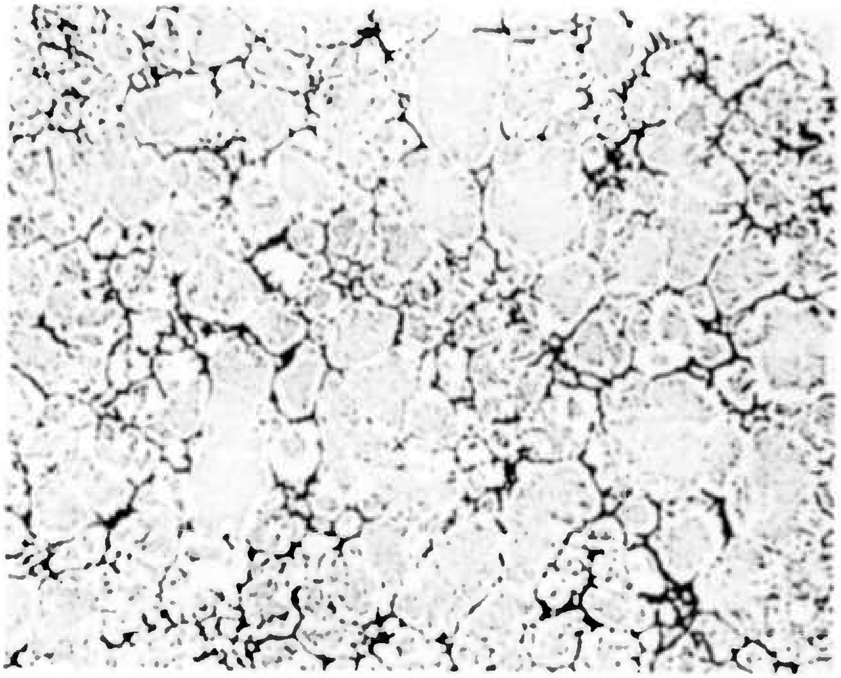

Figure 1. Typical microstructure of 304 stainless steel slurry which was water quenched as it exited from the Continuous Rheocaster. 100X. KOH electrolytic etch.

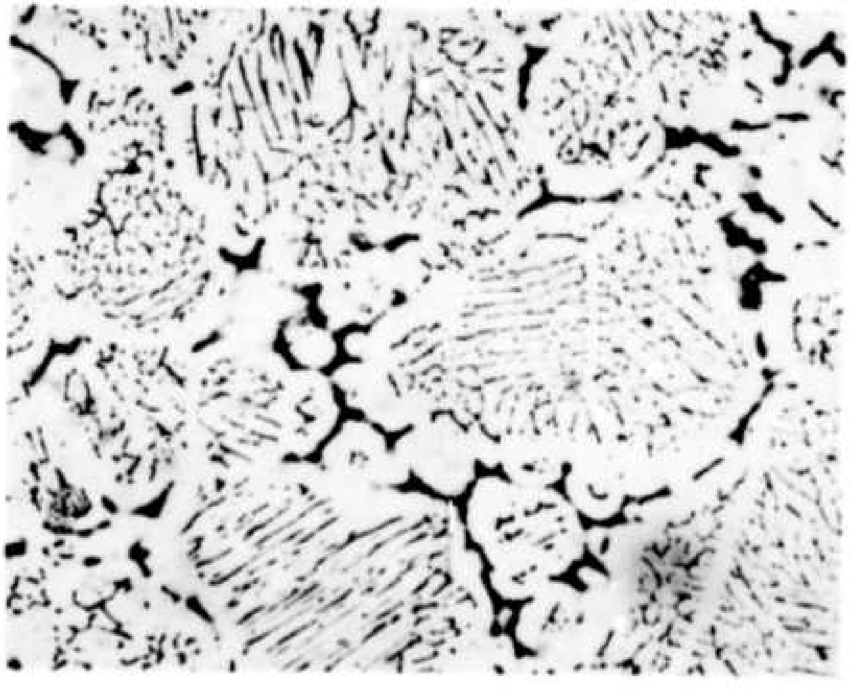

Figure 2. Typical microstructure of 304 stainless steel ingot produced from Rheocast slurry. 100X. KOH electrolytic etch.

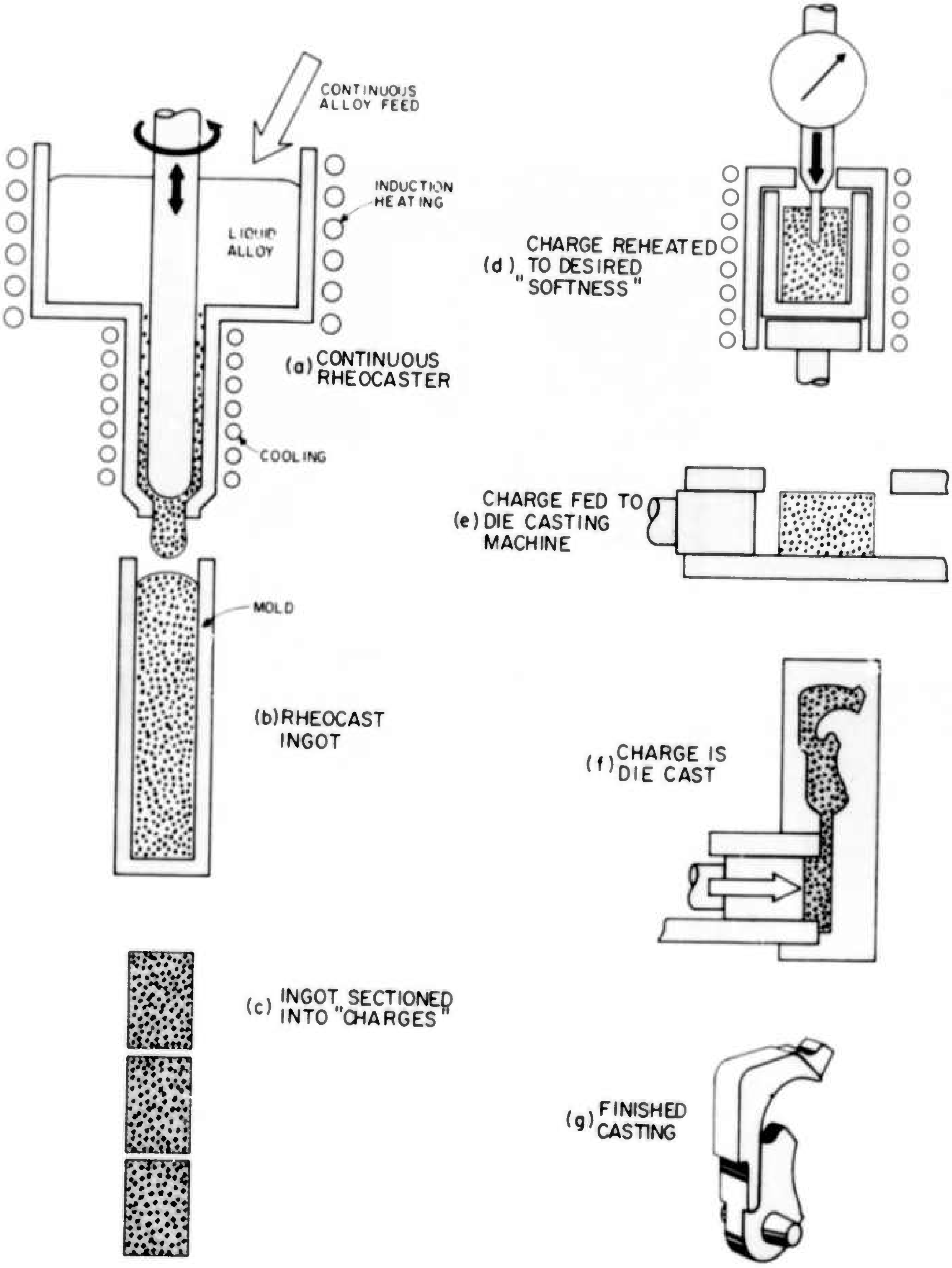

Figure 3. The Thixocasting Process.

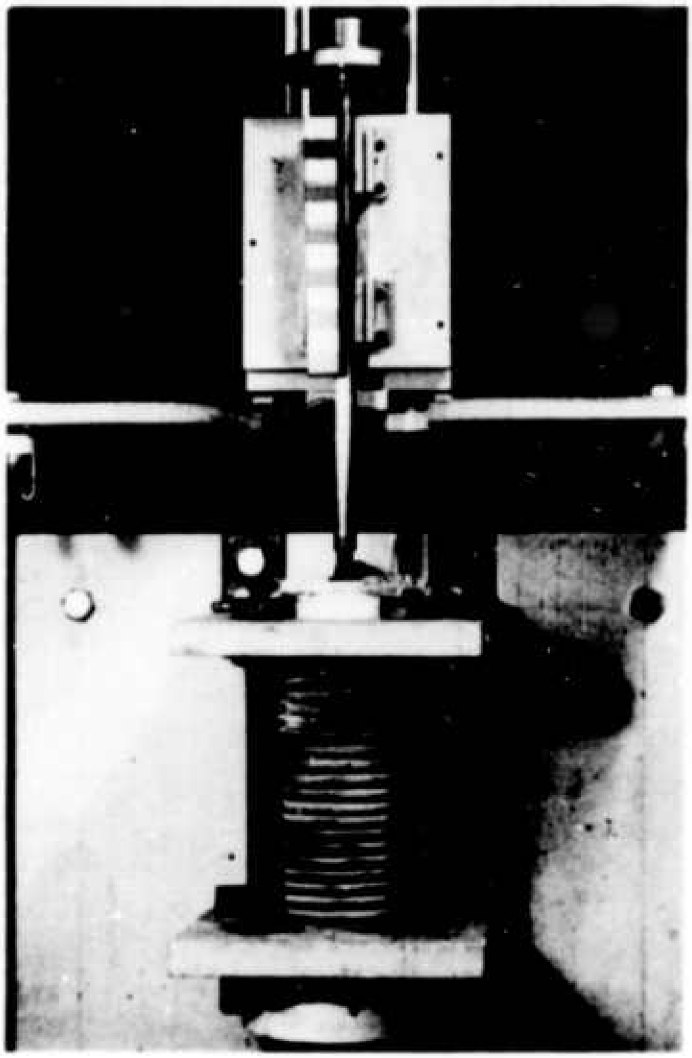

Figure 4. Thixocasting Reheat Furnace and Softness Indicator. 0.2X.

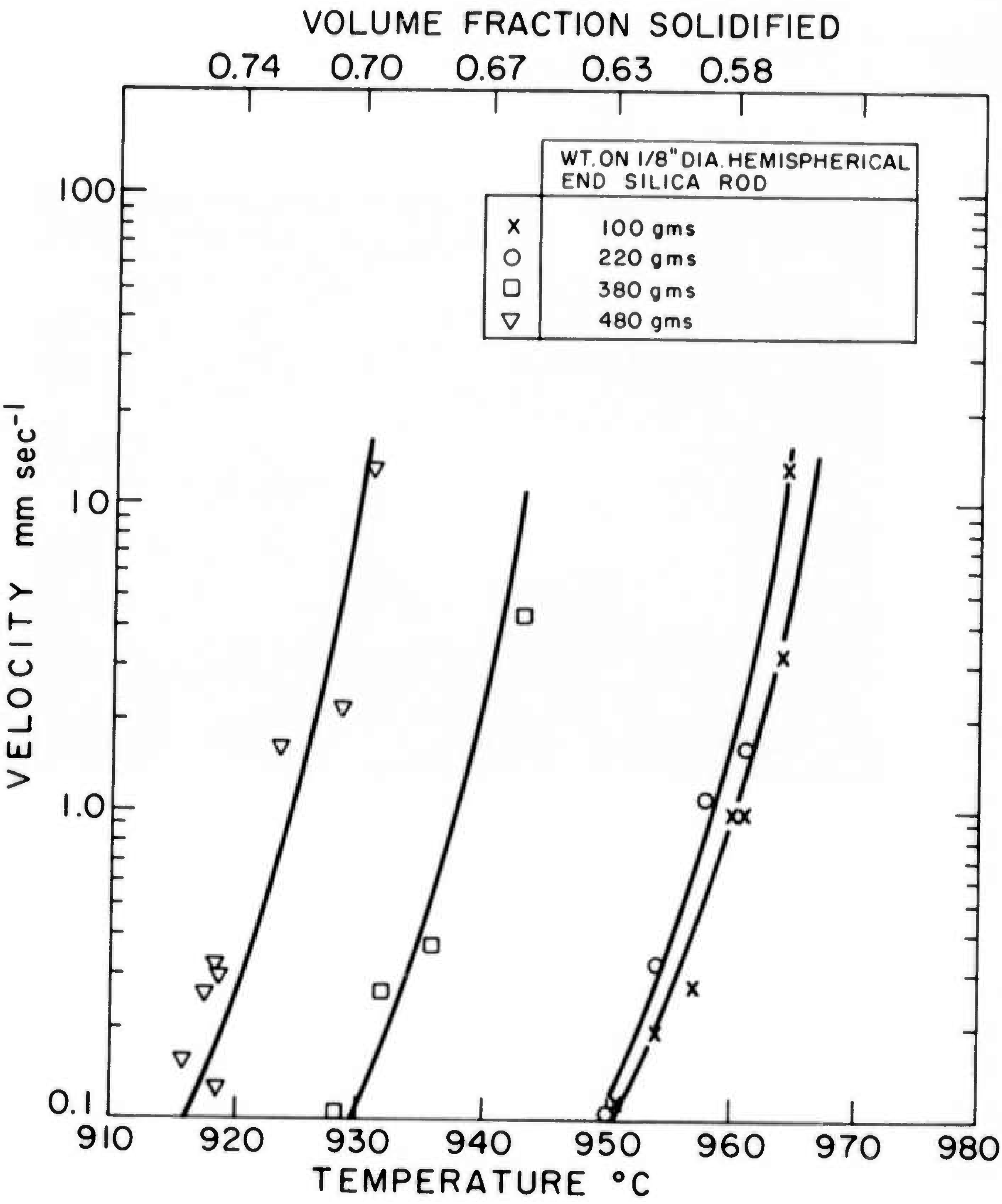

Figure 5. Calibration curves for the Softness Indicator produced by isothermal holding experiments, for Rheocast Copper Alloy 905.

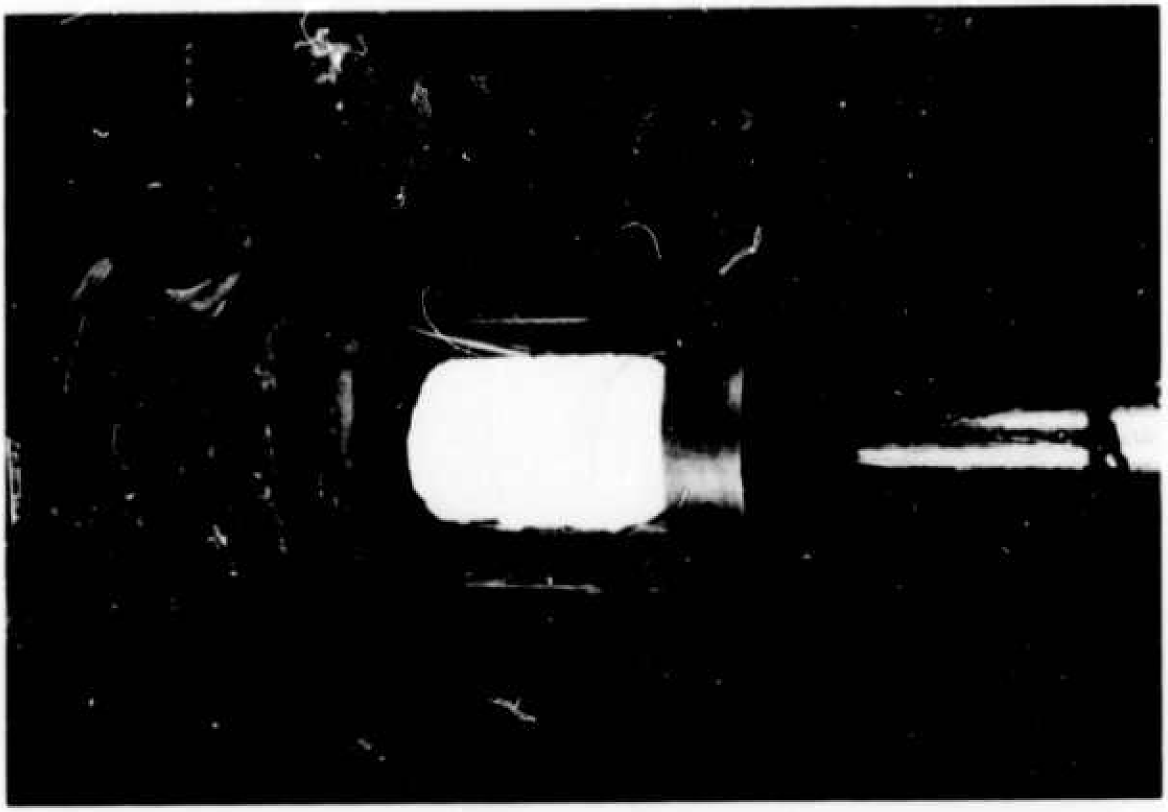

Figure 6. Reheated copper Alloy 905 charge just prior to injection and casting. 0.5X.

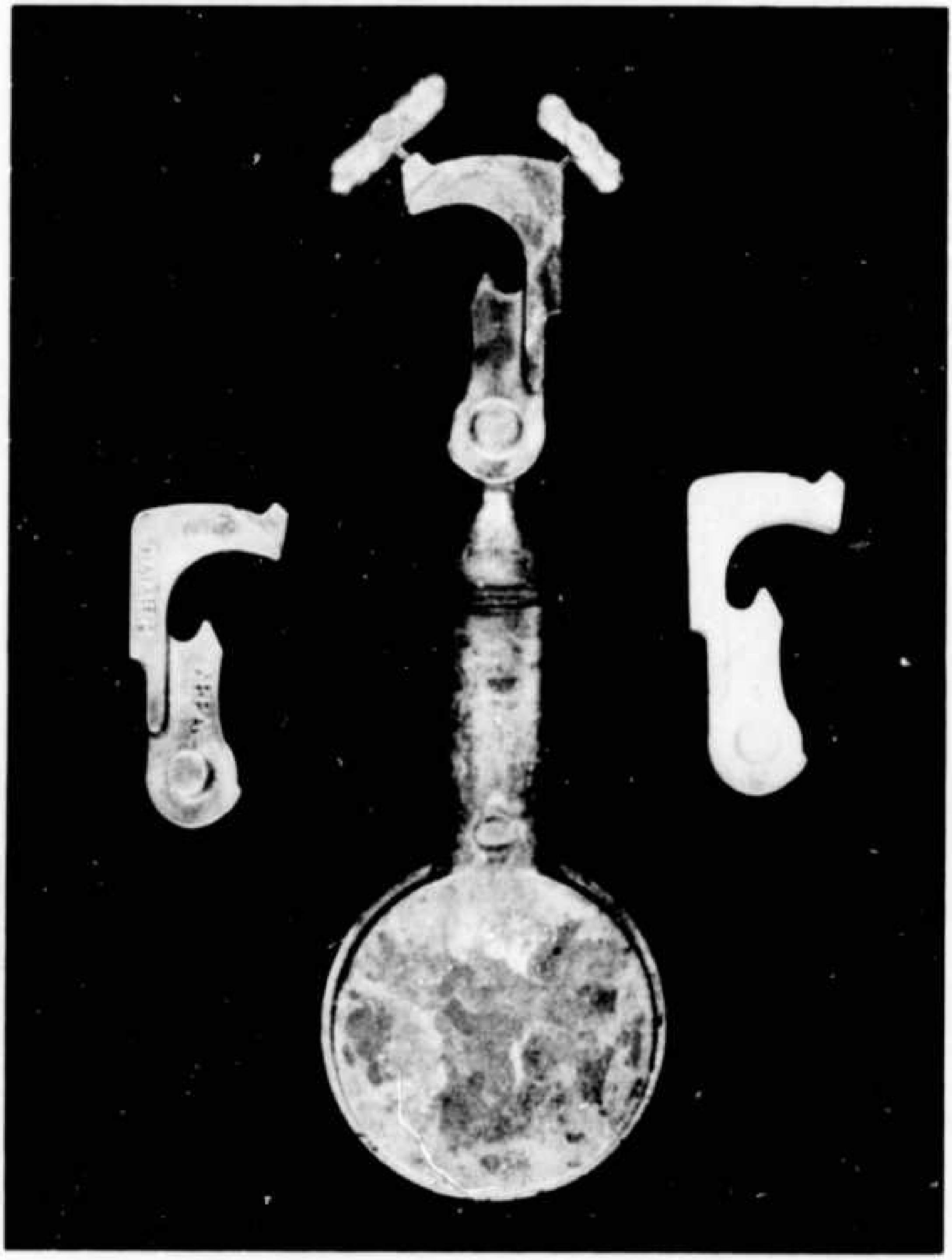

Figure 7. Examples of typical castings in various stages of finishing produced by Thixocasting. 1X.

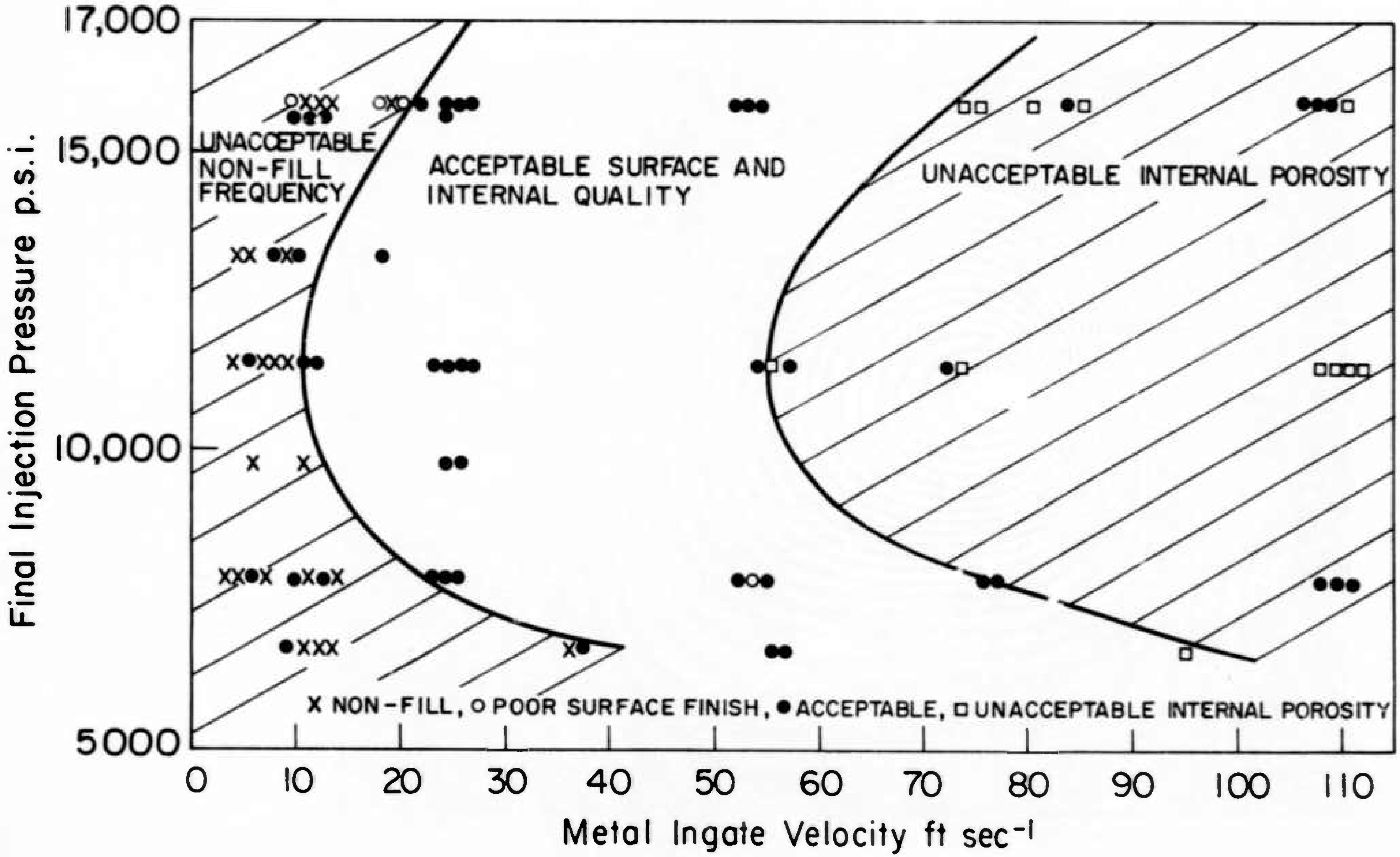

Figure 8. Machine casting parameter optimization for Thixocast Bronze Alloy 905 cast at 0.5 - 0.6 volume fraction solidified. Cast part weighs 0.1 pound with gate cross section of $0.035 in^2$.

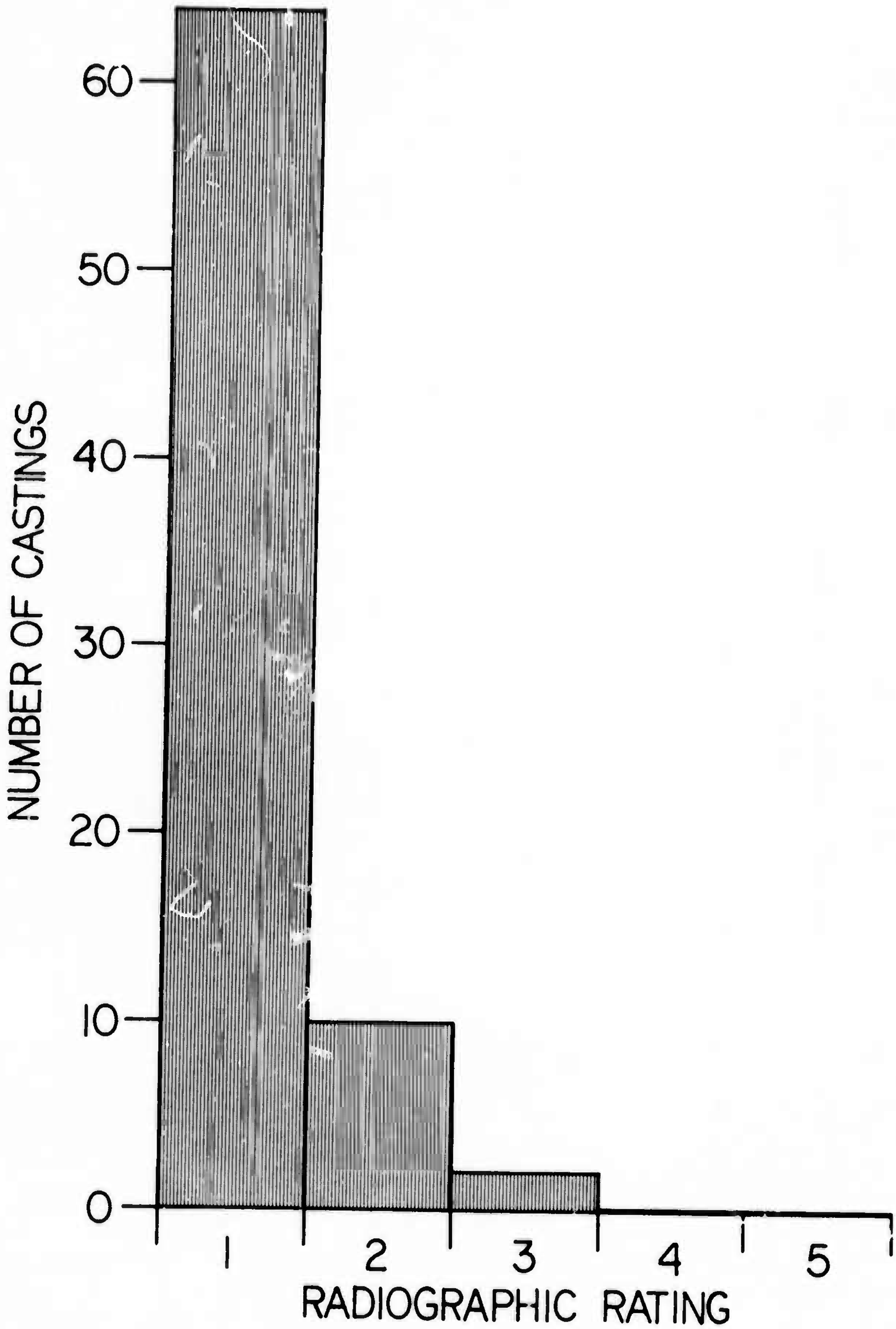

Figure 9. Radiographic rating of a sample of 76 Thixocastings produced at volume fraction solidified 0.5 - 0.6 using the Softness Indicator.

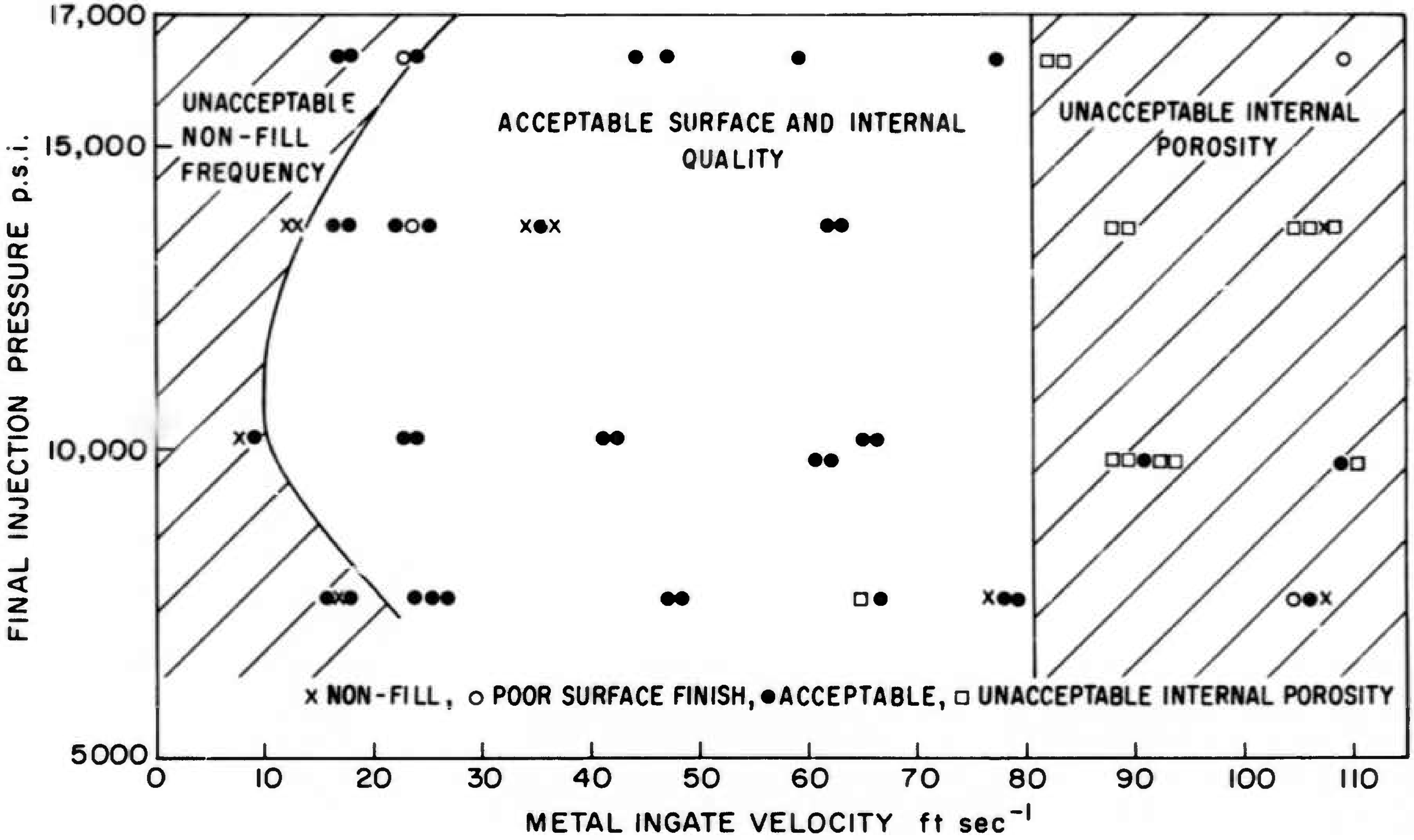

Figure 10. Machine casting parameter optimization for Thixocast 440C stainless steel cast at 0.5 - 0.6 volume fraction solidified. Cast part weighs 0.1 lb with gate cross section of 0.035 in^2.

Figure 11. Microstructure of 304 stainless steel casting. 100X.

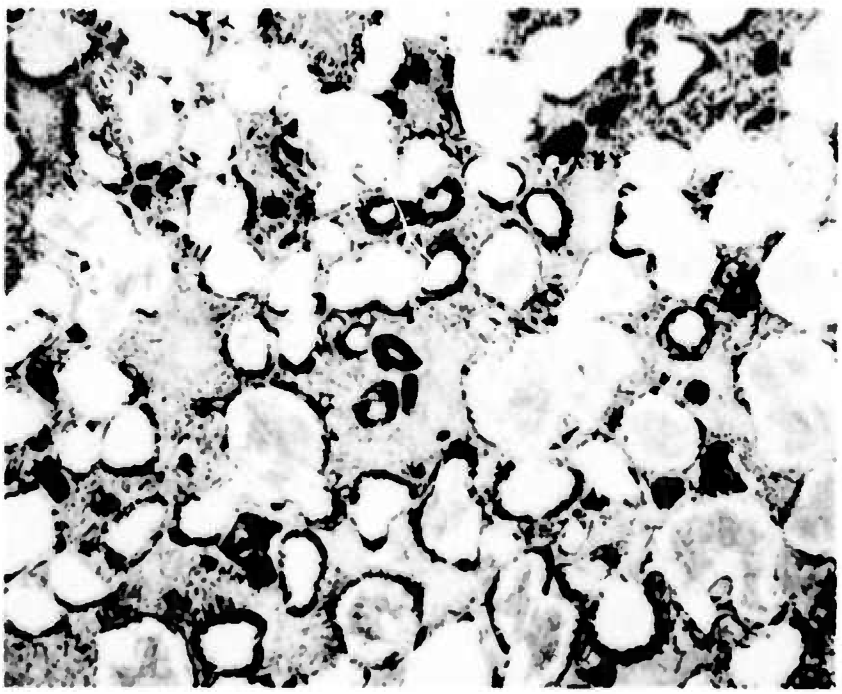

Figure 12. Microstructure of 440C stainless steel casting. 100X.